[0076] To further increase the efficiency of the system, the heat engine **14** may be configured to recover the latent heat of the SMA element **22** when it expels the heat during its transition into a martensitic state. This may be accomplished, for example, by staging multiple heat engines **14** in series, where the cold region **20** of the first heat engine **14** is the hot region **18** of the second.

[0077] To further enhance the efficiency, the following design factors/considerations/design elements described below may be accounted for and/or integrated when constructing the heat engine **14**:

[0078] Air flow Characteristics

[0079] For air heated and/or cooled configurations, the velocity (magnitude and direction) of the air stream relative to the wire length plays a role in the heat transfer ability—especially in the turbulent flow regime; the influence of air stream velocity on the overall heat transfer coefficient is weaker in the laminar flow regime. Considerations such as whether the air flow is parallel, perpendicular, counter, cross or has multiple directions relative to the direction of wire movement and the relative orientations of the spatial temperature gradients in the wire and the air stream also play a role. Fluctuations (direction or magnitude) in the air flow also improve heat transfer by promoting bulk mixing. Finally, the fractional content of water vapor and aerosols (e.g. soot, dust, etc.) also impact the heat transfer conditions by introducing density gradients that drive convective heat transfer or by mediating radiative heat transfer respectively. A heat engine **14** design may account for these air flow characteristics using traditional thermodynamic and fluid dynamic principles.

[0080] Phase Change Heat Transfer

[0081] Phase changes (e.g. condensing steam, evaporation, boiling) are associated with significantly larger (10-100×) heat transfer coefficients than forced convection. Moreover, phase changes occur at a constant temperature or fairly narrow temperature range which makes the analysis and optimal design and control of the heat exchange process easier. Dewetting agents and other surface modifications may be used to promote drop-wise instead of film condensation/boiling and help achieve a further 2-10× improvement in the effective heat transfer coefficient. Very high heat transfer rates can be achieved if the substance undergoing phase change is allowed to come in direct contact with the other substance e.g. saturated methanol or ammonia can evaporate directly from the SMA elements to achieve very high cooling rates at a nearly constant temperature; similarly, water can condense directly on the SMA elements to provide high heating rates at nearly constant temperature. A wire mesh, wiper seal, bed of rags, or other similar technique may be used to mitigate transport of the condensing liquid out of the heating chamber. Evaporative cooling may also be promoted by using jets/nozzles to spray a thin mist of the cooling medium on the wires or using a bed of rags/wire mesh/wiper to apply a thin coat of the cooling medium on the SMA element. The SMA element may be passed through moist steam/cold water saturated chamber or bed of rags to promote higher heating/cooling rates respectively.

[0082] Liquid Heating/Cooling

[0083] Liquid to solid heat transfer rates are roughly 10× higher than gas to solid heat transfer rates. Accordingly, a hot or cold liquid bath may be used to heat or cool the SMA elements respectively.

[0084] Thermal Radiation

[0085] Thermal radiation in the UV, visible and IR bands may be used to heat/cool the SMA elements. Sunlight with suitable focusing reflectors can be used to quickly and uniformly heat SMA elements. Cooled heat sinks with high absorptivity in the range of wavelengths with maximum emittance for the SMA wires can be used to cool the wires quickly.

[0086] Solid-to-Solid Heat Transfer

[0087] Solid to solid heat transfer rates are much higher than liquid to solid ones; they have the same order of magnitude as phase change heat exchange rates. This may be exploited to promote higher heating/cooling rates in the heat engine, for example, by using heated/cooled pulleys over which the elements are passed (though avoiding phase change on the pulley), by moving hot/cold blocks with high thermal capacity into and out of contact with the wires, etc.

[0088] Turbulence/Bulk Mixing Promoters

[0089] Flow modifiers such as extended surfaces, trip wires, inlet swirl generators, twisted surfaces, and other similar modifiers that promote turbulence and the associated bulk fluid mixing have been known to significantly increase the heat transfer rates. A simple staggering of alternate rows of SMA elements in a multi-row arrangement of SMA elements can lead to high heat transfer rates in the downstream rows. Eddies and vortices generated by flow over the elements in the leading row coupled with the acceleration of the flow as it passes by the leading row of elements leads to higher heat transfer rates in the downstream rows of SMA elements. Blades or other flow modifiers attached to pulleys can also be used to improve heat transfer rates.

[0090] Smart Flow Guides

[0091] Guides that direct the flow of the heating/cooling fluid onto the SMA elements can themselves be made of an active element, such as shape memory alloy. The response of this active element to a change in its operating environment can be used to modulate the heat transfer to/from the SMA elements **22**. For example, other thermally activated SMA elements may be used to bypass some flow of the heating fluid if the temperature of the hot fluid rises beyond a safe level.

[0092] Vibration Induced Heat Transfer Enhancement

[0093] Vibration of the wires (e.g. in a plane orthogonal to the wire length) has been shown to increase the heat transfer rates by a factor of 10. Both: high amplitude, low frequency and low amplitude, high frequency vibrations help enhance heat transfer. As such, in an embodiment, such vibrations may be imparted to the SMA element **22**.

[0094] Electric Field Induced Heat Transfer Enhancement

[0095] Electric fields have been shown to improve heat transfer in a medium with conducting particles (e.g. in ionized gas) by directly exerting forces on the charged particles thereby influencing the mixing of fluid in their vicinity. However, electric fields can also promote mixing in dielectric fluid media due to dielectrophoresis. Hence, electric fields can be used to enhance and control heat transfer rates to/from the SMA element **22**

[0096] Regenerators

[0097] Regenerator-type heat exchangers can be used to improve the performance of the heat engine by both providing a thermal buffer to store heat and by using any stored heat to pre-heat the SMA elements. By preventing cooling of the SMA elements below a characteristic temperature, such a regenerator-type heat exchanger can reduce the amount of